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NASA SCIENCE AND TECHNOLOGY
ADVISORY COMMITTEE FOR
MANNED SPACE FLIGHT

Proceedings of the Winter Study on
Uses of Manned Space Flight, 1975-1985

VOLUME I — PROCEEDINGS

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VOLUME I—PROCEEDINGS

The results of a conference held at the
University of California at La Jolla, on
December 6-9, 1968



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PREFACE

In the fall of 1968 discussions between the members of the Science and Technology Advisory Committee and the National Aeronautics and Space Administration suggested that a study of the future uses of space flight capabilities could help greatly in formulating future agency plans. Since several studies had previously accentuated unmanned space science and applications programs, it was felt that a study with particular emphasis on the potential of the manned space program would be a useful next step. Accordingly, plans were made for a four-day winter study at La Jolla, California, on December 6-9, 1968.

The study was convened to consider the application of manned space flight to scientific and technological objectives in the decade 1975-1985. In carrying out this charge the Committee first considered the goals, objectives, and values associated with the national space effort and then attempted to focus on the most important uses of space flight without regard to the question of manned or automated modes. Subsequently, the particular requirements or conditions which would warrant the use of manned space flight were examined.

To provide a basis for this study a number of papers were prepared under the direction of Committee members discussing the use of an assumed manned space station system to support experimentation in various scientific and technological disciplines. Although there was considerable discussion of the potential usefulness of such a manned space station, time was insufficient to permit a thorough evaluation.

Volume I presents the proceedings of the Winter Study. Volume II includes the disciplinary "white" papers, together with a description of the postulated manned space flight capability.

The members of the Committee wish to express their appreciation to their hosts at the University of California at La Jolla, to the NASA staff who made all the arrangements for the conference, and to those personnel of Bellcomm, Inc., who helped prepare the various disciplinary study papers.

March 28, 1969

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SUMMARY OF THE PROCEEDINGS

One decade after the National Aeronautics and Space Act, the nation finds itself with many remarkable space achievements and on the threshold of completing its largest space effort, the Apollo program. Although many possibilities exist for space work of the future, only a limited number of firm plans have been made. Since much of the space program needs to be planned long in advance, and since advance planning in turn affects the developments of later periods, we need now an assessment of the significance of space activity for the future.

VALUES OF SPACE PROGRAM

The values of the space program to the United States lie in many diverse aspects:

Exploration and Discovery

The escape of man from the Earth's surface and his exploration of the Moon, the solar system, and the space beyond represent one of the most exciting frontiers of human discovery. Recognition of its importance and impact on human thought is almost universal. To play a leading role in this discovery our country's program must be well timed and flexible, must pay careful attention to the proper utilization and role of man in exploration, and must put due emphasis on deep space and the planets.

Science

The development of present space technology offers a magnificent opportunity for scientific discovery. A well-planned program of experiments is essential to insure continuity, flexibility, and the participation of the nation's best scientific talent.

Military Security

The development of space technology has supported and will continue to support our military capabilities, and space will be of increasing importance to future military security. The United States cannot, therefore, afford to fall seriously behind in any major areas of manned or automated space capability.

National Prestige

Success in the highly visible area of space operations and exploration provides the world both inspiration and a clear indication of a nation's technical and organizational abilities. Clearly, we are in competition with the U.S.S.R. in the eyes of the world. Internally, the space program as a peaceful demonstration of national strength has become a symbol of national pride and aspiration. The nation must be prepared to compete on a wise and selective basis in all major categories of space activity.

Technological Development

The NASA program focuses the application of technology on challenging goals and makes possible new industrial developments demanding advanced technical competence and great organizational skills. These help give the United States a favorable competitive position in world markets and contribute to growth of advanced industry and creative technical manpower.

Commercial Applications

Economically sound applications of space are already providing benefits in meteorology and communications. Further research and development can be expected to extend these applications into a variety of other areas such as Earth resources surveys, navigation, and traffic control.

Transportation

The ultimate need for transportation on a large scale to orbit, to the Moon, or to the planets should be considered, as well as the possible future use of orbital and suborbital space flight for intercontinental transportation.

NASA PROGRAM

With the perspective of these varied values, NASA's program for the next two decades must make reasonable choices in emphasis and in specific projects among a wide variety of possibilities. Furthermore, planning for the time period 1975-1985 requires a projection of the state of technology for that period.

Because of time limitations during this study, STAC could neither consider all aspects of the space program nor cover appropriately those aspects not closely related to the use of manned space flight. Hence, attention was directed primarily to considering the major goals which involve manned flight, or a combination of manned and unmanned operations. These may be grouped in three categories:

1. Extensive exploration and initial colonization of the Moon.
2. Exploration of Mars, or possibly other planets, including manned landings.
3. The extensive use of orbiting stations for Earth applications, astronomy, and research in the natural and life sciences.

These three classes of possible goals have been considered broadly in the study, with some concentration of attention on the significance of a reduction in cost of launches into space and on the possible uses of manned space stations. In connection with goals of the third class, two types of national orbiting facilities deserve consideration: space observatories and space laboratories. Both may be operated in conjunction with the same space stations.

Observatories would serve the space-oriented disciplines of astronomy and high energy cosmic ray physics, and the Earth-oriented disciplines of Earth sciences and resources, communication, and traffic control. For these disciplines, the unique advantages of a space observing platform, above the atmosphere and at a high vantage point above the Earth, are so compelling that it can only be a matter of time before man utilizes them heavily. Man's role in these operations will probably be most important in deploying, servicing, and repairing complex and versatile experimental equipment, and in assisting in early test and development of new systems.

Space laboratories would serve the life sciences—biomedicine and biology; high energy particle physics; the study of the physics and chemistry of matter in zero gravity; and work on the formation and processing of new materials possible only in zero gravity. The

medical study of man himself in zero gravity is important in preparation for future roles of man in space; a manned space station will make possible, for the first time, prolonged and thorough studies of both man and other biological systems. Man as an experimenter in the physics and materials laboratories would play a role more similar to that in Earth laboratories than in the case of space observatories.

CONCLUSIONS

In general, a balanced space program is desired which not only reaps the returns of present capabilities, but also progresses steadily toward the much greater capabilities achievable in the future. The program must also be balanced in its use of manned and automated operations. The merits of each mode must be considered in the light of the particular objectives of the program involved, with the hope that plans can be laid for an integrated program which best uses all potentialities.

Recognizing that they must be somewhat tentative because of the abbreviated nature of this study, we nevertheless have drawn the following conclusions from our discussions:

1. The benefits to the nation, both internal and international, dictate that the United States remain in the forefront of all major categories of space activity, including

- a. Space sciences
- b. Exploration of the solar system
- c. Manned space flight capability
- d. Economic applications of space flight.

2. It is reasonable to utilize 1/2 to 1 percent of the gross national product to support this nation's civilian space flight program.

3. Within the space flight program the following elements are of major importance and should be strongly supported:

- a. An aggressive automated planetary exploration program as recommended by the Space Sciences Board of the National Academy of Sciences. Options must be kept open for a manned phase to follow the early automated phase.

- b. An economic applications program of the general nature recommended by the 1968 Summer Study on Space Applications carried out by the National Academy of Sciences.

c. A continuation of lunar exploration following the Apollo landing as recommended by the Lunar and Planetary Missions Board of NASA.

d. A vigorous program of astronomical observations in Earth orbit along the general lines recommended by the Astronomy Missions Board of NASA.

e. The extension of manned space flight capability in Earth orbit to longer duration and to permit application for scientific and technological purposes.

4. Achievement of a manned low-cost transportation system is the keystone to the future development and large scale practical application of the space program. Development of such a system and plans for its effective use deserve high priority.

5. The use of a long duration manned space station appears to be a logical step in the evolution of manned space flight capability. It offers considerable potential support to the scientific and technological programs which appear desirable in a number of disciplines, and is necessary as a precursor to eventual manned planetary exploration. Such a space station should be designed to support men in the weightless condition unless unexpected biomedical problems are encountered or overwhelming engineering advantages for artificial gravity are discovered.

6. It is generally agreed that strong arguments exist for placing observatories and laboratories in Earth orbit. Large, complex facilities and instruments for astronomy, Earth applications, space physics, life sciences, and new materials development all have interesting potentials, and all can profit from manned attendance. Relative emphasis among these activities, and the extent of manned attendance desirable in each, must be decided by appropriate studies and early experiments.

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INTRODUCTION

The more important elements of the rationale for a national space program have been recognized by policy makers since the inception of a substantial U.S. effort, and this effort has been broadly supported. But the many facets of the space program are seen in various lights by various individuals or groups, and hence there has been vigorous debate about the relative values of its different aspects and their importance compared with other national interests. Major facets of the space program may be listed as follows:

1. Exploration and discovery
2. Science
3. Military security
4. National prestige
5. Technological development
6. Commercial applications
7. Transportation

Thus the U.S. space program has many reasons, no single one of which can provide continuously and to everyone a very satisfying justification. Many of the values, such as exploration and scientific discovery, are simply not translatable into directly measurable advantages which can be compared with the large expenditures required. Yet taken together, the sum of all values in space work dictate an urgent and substantial program. There is probably no thoughtful U.S. citizen who can contemplate with equanimity the prospect of looking backward some years from now on what surely will be one of man's great achievements, the conquest of space, without his nation having played a proud and important role.

The U.S. space program has had a share of difficulties along with successes. However, if one assesses space accomplishments at this point—the development of enormous boosters and reliable circuitry; the extensive and beautiful work toward a better understanding of the Moon and planets; dissipation of many deep concerns over weightlessness, hostile radiation, and difficult lunar surface conditions; the development of weather and communications satellites; and the outstanding progress of the Apollo program—there is no doubt that the nation's space achievements are remarkable.

We expect that the enormous undertaking to land men on the lunar surface by 1970 will be successfully completed on time, and within the originally expected costs. Yet now less than one year

from such an accomplishment, the nation finds itself in disarray and uncertainty in the problems of where and how to proceed in space work after a successful lunar landing. NASA's funds have decreased successively for several years. Funding of the Apollo program has been adequate to maintain its schedule, but a number of important plans for planetary exploration and for additional manned operations have been cancelled or held in abeyance, and the next major steps after the coming lunar landing are not clear. These problems come, in part, from the pressure of other demands on the nation's attention and, in part, from the very success itself of our space efforts.

With the exception of the planned lunar landing, most of the nation's space program has been subject to rather frequent shifts in emphasis, including substantial redirection of efforts, and cancellation. Some of these changes have of course been beneficial, but all have made planning and continuity difficult. The Apollo program has stood as a firm commitment and the hard core of a major part of NASA's effort. With its completion, there are few other aspects of the space program which stand out with similar clarity and immutability and which serve in the same way to unify our efforts, so that planning for space exploration and development takes on new difficulty.

SPACE PROGRAM VALUES AND GUIDELINES

With completion of a lunar landing and the development of new potentialities, the many different facets of the space program present almost too many choices. In addition, so much technology has been developed that the temptation is strong, with some justification, to capitalize on what we can achieve as a result of these recent developments rather than pressing on toward still others.

We are thus at a point where reassessment is clearly needed. Some of the many centrifugal aspects of the space program which exert pressures for a change of emphasis and tactics, after the immediate thrust of Apollo is over, can be described under the seven major facets listed above.

EXPLORATION AND DISCOVERY

Man's escape from the Earth's surface, his exploration of the Moon and planets and further penetration, at least by instruments, of the depths of space beyond the solar system, represent one of

the most exciting and appealing frontiers for human exploration. The recognition of its importance and its impact on human thought is almost universal. This aspect of the program places particular emphasis on the timing of activities, since to discover, one must by definition be first. Further, the program must be flexible since, to successfully exploit any strategy, we must be able to accommodate the changes dictated by new discoveries.

It is evident that these values require emphasis on the deep space elements of the program, particularly the exploration of the planets. Exploration on a scale above some minimum, or with more than some minimum level of thoroughness, will clearly profit from the presence of man. Hence the contribution of manned flight to these aspects of the space program must be carefully considered.

SCIENCE

The development of the present space technology offers an unparalleled opportunity for scientific discovery if properly applied to the performance of experiments. The progress already made in astronomy and the natural, life and Earth sciences can be expected to continue through the use of sophisticated, flexible, and complex experimental facilities in Earth orbit which complement ground based research. As examples, a good observatory outside the Earth's atmosphere will have an enormous effect on astronomy and, if life is discovered outside the Earth, biology could be revolutionized.

To ensure the best results for the space science program, both continuity and flexibility must be provided in planning. Finally, every effort must be made to involve the scientific talent of the nation in all phases of planning and operations.

MILITARY SECURITY

The space program has already made significant contributions to the military security of the nation typified by the systems referred to by President Johnson when he commented that one security aspect of the space program has alone justified ten times all the money the nation has spent on space work. Space technology will clearly be of importance in future defense of the nation. The United States cannot, therefore, afford to fall seriously behind in controlling extra-atmospheric space. It is expected that this support to our military security through the development of technology and demonstration of space capability will continue. Potential contributions may be made in the areas of arms control, satellite inspection, and ballistic missile defense. The value of the development of

manne l flight capability to these areas is indicated by the support already provided to the Manned Orbiting Laboratory program of the U.S. Air Force by the civilian Gemini and Apollo programs.

This aspect of the program requires the continued coordination of technological development between the Department of Defense and NASA to the maximum practical extent. However, the benefits of a civilian space agency, recognized by the founders of NASA, make it important to maintain the present delineation of military and civilian responsibilities and missions.

NATIONAL PRESTIGE

Marked success in space exploration is powerful evidence of a nation's technological and organizational skill, and new, incisive steps, a reflection of boldness and imagination. Thus, a strong position in space exploration and technology, with all its demands and visibility, can have an effect parallel to the grim show of military power itself, and yet happily much more benign. This involves a number of significant national and international implications. In the international sphere, we are in competition with the Soviet Union in the eyes of the rest of the world, and the results of this competition can have a substantial effect on international views and evaluation of the future. These can be gaged in part from reactions to recent successes of the Apollo program. While we need not lead other nations on every space development, it is highly important to compete successfully in a broad sense.

Internally, the space program as a peaceful demonstration of national strength has become a symbol of national pride and aspiration, as shown by the apparent effect of successful space operations on the national morale. Because of the ease of identification, the manned space flight program contributes most strongly in these areas. However, the agency has an obligation to describe the automated program in such a way that public appreciation of, and identification with, unmanned missions is increased.

It can be concluded that, because of the position the space program has come to occupy in both the national and international areas, the nation must be prepared to compete on a wise and selective basis, in all major categories of space activity. These may be listed as follows:

1. Space sciences
2. Exploration of the solar system

3. Manned space flight capability
4. Economic applications of space flight.

Further, the space program should be conducted in such a way as to ensure timely development of the space technology on which these categories of endeavor depend.

TECHNOLOGICAL DEVELOPMENT

A highly successful space program gives the world an appearance of technological and organizational leadership; its stringent demands, in fact, develop and require them. A major portion of the NASA resources is spent for technology on challenging goals. These are important to the nation's military capability and industrial development. A successful space program also develops and requires unusual technological and organizational leadership. The overall results are exemplified by the demonstration of capability to build complex systems that provide first-time reliable performance while using a diverse contractor structure. These factors are probably important in giving U.S. industry a favorable competitive position in world markets. The technological challenge of the space program furthermore provides motivation for the entry of young people into scientific and engineering professions, thus increasing the technological manpower of the nation.

COMMERCIAL APPLICATIONS

Applications of space flight in the areas of meteorology and communications have already been demonstrated to be economical because of direct material benefit to civilian life. One can expect progress in these areas to continue and applications to extend into the areas of Earth resources survey, navigation, and traffic control. In a longer range context, the particular environment of space offers potential for the production of new materials and artifacts of commercial value.

TRANSPORTATION

The space program has developed a transportation capability to move men and materials over large distances at high speeds. Historically the gap between the development of such a new

transportation capability and larger scale usage has always been short. Consequently, consideration of the application of orbital and suborbital space flight to intercontinental transportation should not be neglected.

Although large-scale utilization of lunar and interplanetary transportation cannot now be predicted on purely rational grounds, there may be an ultimate need for such a capability.

PROGRAM DISCUSSION

The appropriate pace, as well as the appropriate program, for the space effort demands careful judgement. Many citizens are confident of Apollo's impending success, and somewhat confident that if we are not far ahead of the U.S.S.R. we are at least not frighteningly behind; thus, some of the emotional imperative behind space development has slackened, and a sense of urgency must now be based more completely on logical conviction.

A lunar landing is still a breathtaking goal. Yet even before it is completed, the nation must, in order to proceed smoothly toward future achievements, make plans for future undertakings to which our mood and imaginations are not yet adjusted. We cannot simply adopt a wait-and-see stance, because efforts of the NASA team and operation of its facilities cannot be turned off and on like a light switch. For efficiency and effectiveness a continuous program and planning a decade or more in advance are needed—a task which challenges all the nation's wisdom and imagination.

The present study focused on a number of disciplinary areas, both objectives likely to be attacked in the 1975-1985 decade, and the proper role of manned space flight in this attack. The most likely directions of nonmilitary development of the manned space flight capability during the next few decades are as follows:

1. Extensive exploration and initial colonization of the Moon.
2. Exploration of Mars and Venus, including a program to place men on one of them (probably Mars) and return, coupled with exploration of the far planets.
3. The use of Earth orbiting stations to advance the fields of astronomy, space physics, Earth sciences and applications, life sciences, and new materials development.

Those familiar with military space developments will clearly recognize that use of space for military purposes cannot be

separated completely from other space developments. Classification and policy reasons dictate that military applications will not be overtly treated here.

In the remainder of these proceedings some of the above directions are discussed in more detail. Many of the committee's findings are based on the various disciplinary papers presented during the study (see Volume II).

REDUCING THE COST OF SPACE OPERATIONS

If space travel, space science, and space industry are ever to become a normal part of human experience, the large costs now required for each space operation must be drastically reduced. The prime reasons for the high cost lie in the fact that the vehicles are expensive and typically used only once. If costs are to be reduced, either the cost of the vehicle must decrease, or its utilization must be greatly increased while keeping the cost of utilization low. This presumes, of course, that space operations will be adequately numerous so that the cost of development of new vehicles is not a prohibitively large fractional contribution to the total costs.

SHUTTLES

The need for the development of new launch and logistics vehicles to provide a transportation capability to and from Earth orbit at costs more than an order of magnitude lower than currently achieved is clearly of great significance. Such vehicles could substantially change the utilization of many possible space operations. A low-cost transportation capability is required if the operating costs of manned space laboratories and observatories are to be reduced to a level which will permit their extensive exploitation for scientific, technological, and economic purposes.

For very large reduction in costs, it is apparent that the essential feature needed is vehicle reusability with low-cost maintenance analogous to current aircraft techniques. With the use of appropriate system design and high performance technology it appears feasible at reasonable cost to undertake development of an Earth orbit shuttle system. Such a system, for use in 1975 and beyond, would rotate crew and carry discretionary payload.

Such a vehicle, possessing the potential for reducing the incremental cost of transportation to orbit to about \$50 or possibly lower per pound of payload, would have an enormous effect on the evolution of the space program. Consequently, initiation of work in all areas necessary to achieve a low-cost transportation system should be given high priority.

SPACE STATIONS AND OBSERVATORIES

To permit the effective use of Earth orbital space stations and observatories it is necessary not only to provide low-cost transportation but also to reduce in-orbit costs. One effective way to achieve low cost for orbital operations is to provide a spacecraft or space station capable of long duration and high intensity operation. Its cost can then be amortized over its total return, namely, a long period of use and a large quantity of data. A manned space station, for example, should be capable of being revisited and replenished at appropriate intervals. In these respects it would be analogous to ground-based facilities while permitting the space-based opportunities for some of the scientific research, technological investigations, and economic applications discussed in this study.

Such a space station should be large enough to provide accommodation for a crew possessing necessary skills for expert conduct of experiments as well as for more conventional spacecraft functions. Further, it is to be expected that the system would be modular in nature to permit flexibility in meeting evolving needs as well as to permit flight in different special configurations and orbits. Such a system is well within the range of present technology.

EXPERIMENT PAYLOADS

The cost of developing scientific instruments for space use is now on the order of \$10,000 per pound. In view of a potential transportation cost of \$50 per pound this is excessive (even at some present booster costs this is excessive), and every effort should be made to reduce instrument cost by at least an order of magnitude.

If such a reduction were to be achieved, a large space telescope might cost about \$100 million and could be maintained at an annual cost of about \$15 million—assuming six flights per year of a low-cost shuttle vehicle. Such costs are comparable with the nation's expenditures for ground-based astronomy and similar to

those for major new scientific facilities on Earth, such as the proposed National Accelerator Facility. If such cost levels can in fact be achieved, a space observatory is strongly recommended.

To achieve low net costs, the instruments should be usable over a long period of time. This indicates design to permit scientific flexibility, maintainability, and replenishment.

Finally, it is apparent that payload cost generally dominates transportation cost even under present circumstances, and that this would become extreme with the introduction of low-cost transportation. Consequently, efforts should be made to maintain a reasonable balance between payload and transportation costs, and to evolve toward payload doctrine and designs which may be heavier than present ones, but which minimize the combined transportation and payload costs.

THE LUNAR PROGRAM

INTRODUCTION

The lunar space program can logically be divided into two phases—exploration and exploitation. The exploration phase has involved the Ranger, Orbiter, and Surveyor automated programs; manned exploration begins with the first Apollo landing. If the results from Apollo justify the program, we may have progressed by 1975 to the point where lunar exploitation can commence and continue to grow throughout the 1975-1985 period.

For the exploitation phase, the features of a substantial lunar base are sufficiently attractive to warrant a brief discussion. It should be noted, however, that this phase may involve a continuation of the multiple site activity required for exploration, as an alternative to the lunar base concept. Because the exploitation phase must be supported by the results from precursor exploration, a brief discussion of the necessary features of this earlier activity is presented.

THE EXPLORATION PHASE

Two main tasks should be undertaken during the early phase of exploration. First, the Moon should be explored and a range of scientific experiments must be conducted to determine the desirability of subsequent exploitation for scientific, technological, or

economic reasons. Second, Earth-Moon transportation of sufficiently low cost to provide reasonable support for a large long-term manned activity should be investigated and proven.

There are other, lesser, tasks which need to be undertaken by the exploration phase, principal among which is the provision of lunar surface mobility systems.

The Lunar Program Until 1975

A balanced program of manned and unmanned exploration of the Moon must be started and phased with the first few Apollo flights, and continue at least until 1975. Such a program (similar to that described in Appendix C—Lunar Program) would begin with the use of extended stay time for the astronauts on the lunar surface. It would include orbital studies of the lunar surface by a variety of sensors, and would proceed with the capability of landing missions with both a manned and an unmanned component. Increased surface mobility is also needed very soon, and might be provided by small lunar flying units, and/or a lunar roving vehicle which would operate over a few tens of kilometers manned, and perhaps over hundreds of kilometers unmanned. A program of this kind allows detailed geological studies of a number of lunar sites, and also allows for a range of experiments in lunar physics and chemistry. Additionally, it provides the necessary base of experience for men to live and work usefully on the lunar surface.

A Low-Cost Transportation System

During the exploration phase one must determine if a system can be developed to move men and materials from Earth to the Moon and back at a "reasonable" cost. A major part of such a system would probably be reusable vehicles. Whether only a study is needed, or whether a considerable effort must be expended in developing prototype vehicles has to be decided. This work should progress at a rate consistent with that of the lunar exploration.

THE EXPLOITATION PHASE

The use of a lunar base as a central item during the lunar exploitation phase possesses several significant aspects. The base would represent the extension of man's domain in the solar system

and an opportunity for international scientific and technologic cooperation. The experience gained through the preparation of such a base could be expected to contribute materially to longer range manned activities on other planetary surfaces. While the potential for commercial lunar exploitation is not at present very clear, the low-cost transportation considered necessary for extended base operation substantially improves its possibility. Finally, from the long-range point of view of history, a self-sustaining lunar base would provide the first example of extraterrestrial colonization, and some basis for its evaluation.

Guidelines for lunar science of the future await the results from the Apollo program. They will give specific direction to the future study of the Moon. There are, however, some general statements that can be made about the areas that will probably warrant detailed study.

The geological sciences would comprise the first general area of lunar base utilization. Many initial questions regarding the origin and composition of the Moon will be answered by the Apollo program, e.g., isotopic ratios, compositional data, the occurrence of organic chemical complexes and meteorite content. Follow-on missions with extended traverses will increase the geological knowledge of the surface. The lunar base, however, could provide time to conduct detailed studies, including some sample analysis, and would constitute a center for further prospecting for lunar resources.

The general question of the characteristics and geophysics of the interior of the Moon may be best attacked at a lunar base. Passive seismic nets might be established by 1975, but a passive short base-leg array and active seismic studies might be better accomplished from a base. The determination of the lunar heat flow probably requires careful drilling to a depth of some tens of meters, possibly unattainable on early missions. Such drilling would provide material for solution of geochemical and geological problems. A base located near one of the "mascons" would provide an interesting opportunity to attempt to determine the nature of the material involved.

We turn now to other scientific tasks that would use the Moon as a base. Use for nonlunar science will depend in large part upon the relative suitability of the different vantage points, i.e., Earth orbit versus lunar surface. Assuming a favorable surface environment (low dust, radiation, and meteoroid levels; good soil stability; etc.),

astronomical observations may hold particular promise. While measurements can be made from Earth satellites, a Moon base may provide certain advantages. For example, it will provide 14 days of uninterrupted darkness. In the X-ray and gamma-ray spectral regions, the lunar horizon can be used as an occulting edge to determine the location and intensity of galactic and extragalactic sources. Finally, a lunar base could enable one to construct radio astronomical arrays for studies of the long wavelengths of the spectrum, particularly on the back side of the Moon. Such experiments may have been done in the first phase, but they would be needed also in the second phase.

In lunar space physics, a continuous study of the solar wind incident on the Moon and of the plasma-surface interaction could be combined with studies of induced electrical and magnetic fields. A lunar base would provide a station for studies of possible gravitational radiation, and an alternate to Earth orbital observatories for work on high-energy particles and cosmic radiation.

In the area of the life sciences, the Apollo missions will again provide information which will dictate the next phase of study. If complex organic molecules and available water are discovered on the Moon, we can expect a major impact upon the field of exobiology.

In space medicine, a lunar base would provide an opportunity for astronaut physiologic and life support studies.

Long-term technological objectives of a base would focus on several items, subject to the advances made in earlier lunar programs and in other phases of manned or unmanned space activity. Listed below, they have been discussed in detail in Volume II.

1. Development of lunar resources with the aim of base self-sufficiency.
2. Use of the Moon as a launch platform or refueling station for planetary exploration and/or continued lunar exploration.
3. Experimental colonization.
4. Quarantine facilities for extraterrestrial materials and for man returning from planetary missions.

PRIORITIES IN THE EXPLOITATION PHASE

The first tasks in the exploitation phase following the base buildup would be mainly scientific. Dependent upon early exploration results, it is likely that continued lunar investigations would

rank high, especially with regard to the solution of complex geological, geochemical, and geophysical problems which are significant in comparative planetological studies.

Unless there are surprises in the exploration phase, life sciences and exobiology at a base may fall lower in priority and later in time than the investigations mentioned. Space medical studies will, of course, be a natural by-product of the existence of an inhabited lunar base.

Technological objectives seem to fall low in priority and to come late in time.

THE PLANETARY PROGRAM

The planetary program has recently been subjected to extensive study by the Space Science Board of the National Academy of Sciences. The results of this thorough review are contained in their excellent report (Planetary Exploration 1968-1975, Report of a Study by the Space Sciences Board, Washington, D.C., June 1968).

The present discussion of the planetary program draws on results of the deliberations during 1968 of the Space Science Board of the National Academy of Sciences, but takes a somewhat different view, particularly because the time frame being considered is of a longer range. This discussion is based on the conviction that manned exploration of the more hospitable planets is inevitable and that the requisite capability can be provided in the early 1980's. For reasons which are not directly related to the mission returns, but which are related to the values of the space program discussed in the Introduction of these proceedings, it is believed that the option of conducting such exploration at an early opportunity should be maintained. While the decision to proceed with a manned planetary mission may not be made on the basis of the mission returns alone, the implementing program should be structured to maximize the returns. Our current understanding of the planets suggests that consideration be given to the following exploration modes: Mars flyby with surface sample return, orbital reconnaissance of Venus, and Mars landing and return. Opportunities for such missions with reasonable energy requirements will occur in 1982, and there will be later opportunities at intervals of approximately two years.

To provide a focal point for structuring a manned planetary program, a target date of 1982 and the Mars landing mode, which affords the greatest degree of technological difficulty, are assumed here for discussion. Achievement of the operational capability in that year would require initiation of system design in about 1975. The principal design prerequisites include data on the planet and its environment, on man's requirements in long-duration space flight, and on long-duration spacecraft systems and subsystems. The first of the foregoing can be obtained through an automated planetary program. Some of these projects are already underway but increased emphasis is required in the mid and late 1970's. The other prerequisite can be achieved by initiation of a space station program which would provide a long-duration manned mission in the 1974-1975 period.

The automated planetary program suggested to provide the required precursory information by the mid-1970's should emphasize early, sustained exploration of the surface of Mars and provide early definition of its atmosphere and its particles and field environment. Exobiological data should be obtained before possible planetary contamination due to manned exploration occurs. Knowledge of the Venusian atmosphere and environment should be expanded. It is also necessary to have an orbital mapping system in the mid-1970's to provide data for the classification of terrain types and for the selection of possible landing sites.

To obtain this information and meet the scientific objectives as outlined in the recent report of the National Academy of Sciences, an aggressive automated program must be preserved. In addition to the 1969 Mars Mariner missions the program should include orbital missions and flights of orbiter/landing systems of increasing sophistication to Mars. Flyby and orbital Venus missions should be conducted together with the deployment of atmospheric probes.

In addition to the investigation of the near planets, advantages should be taken of the opportunities for far planet investigations, typified by the Venus-Mercury and "Grand Tour" missions possible in the 1975-1980 time period.

Achievement of the capability for manned planetary exploration in the early 1980's requires that a decision to proceed with a space station program be made very soon and that automated Mars mission projects which have been initiated be continued and augmented in the 1975-1980 period. It does not require a commitment to a manned planetary program for several years. It is

believed that the option should be kept open, but that any decision on a mission target date should be postponed.

SPACE OBSERVATORIES

The disciplines discussed under "Space Observatories" are astronomy, high energy cosmic ray physics, Earth sciences, and Earth applications. The activities involve the reception of information through space-oriented or Earth-oriented instruments, some degree of on-board translation of information, and transmission to other locations. As the proposed observatory systems become large, the usefulness of manned deployment, maintenance, adjustment, and updating of the system becomes more apparent, qualified by cost considerations. The prospects for advantageous use of man in modes such as visually collecting information, on-board decision-making, or information filtering are not as clearly apparent, and are generally not supported.

ASTRONOMY

Program

In astronomy we wish to learn about (1) the status and history of the universe, (2) the status and history of the Sun and the solar system, (3) the universality of physical laws and their application to new processes, and (4) the existence of extraterrestrial life. In order to attack these goals, observations are required of the Sun, planets, stars, galaxies, and the matter distributed between them in the broadest possible range of wavelengths. In some cases, very high spatial resolution is desired, as is high spectral resolution and photometric accuracy or energy discrimination.

The great advantages of space versus ground-based telescopes arise from (1) opening up the entire available electromagnetic spectrum, (2) improving the best attainable angular resolution far beyond that set by atmospheric "seeing," and (3) decreasing background light scattered by the atmosphere.

Instruments

A number of major astronomical instruments will be needed to perform the detailed observations required over more than 15

decades of the electromagnetic spectrum. Various large instruments are required for the X-ray, optical, and radio wavelength regions, as well as unique instruments for solar observations.

In most cases, astronomical instrumentation consists of a telescope (photon collector) with a variety of detectors at the focus. The telescopes for space envisioned here would be very large to permit observations at high resolution and observations of faint objects. Such telescopes would be used for decades if they could be made to last that long. The requirements for detectors and various analyzers at the focus would change as technology and scientific needs evolved.

For the purpose of this study we can consider four general locations for the astronomical instruments: (1) the Earth, (2) low Earth orbit, (3) high (synchronous) orbit, and (4) the lunar surface.

Except for some radio wavelengths, astronomical observations from the Earth are degraded or impossible. To obtain the observations required, instruments are needed in space. We shall probably need, eventually, several space astronomical observatories, with some instruments in low Earth orbit, several instruments in synchronous orbit, and some on the Moon. It appears at this time that the orbital sites should be utilized first until more knowledge is gained about the Moon.

Roles of Man

The possible roles of man, assuming that he is available, fall into five general categories: (1) to maintain, repair, and replace faulty subsystems, (2) to update, modify, and replace subsystems, (3) to deploy the initial structure, (4) to align and calibrate, and (5) to operate instruments as a scientist-astronaut.

Man as a scientist in space is apparently not necessary to astronomy. However, when we are dealing with large, complex, and hopefully long-lived telescopes, we are faced with an economic decision as to whether man should maintain and update the instrument in space. Instruments such as the long focus solar telescope appear more feasible if manned deployment and adjustment are available.

Modes of Operation

Several modes of operation in space are possible: (1) Completely unmanned instrument, which upon failure would be replaced by a

new instrument. This appears to be an unlikely approach for a very expensive space telescope. (2) Observatory integral with a manned space station. Potential pointing and contamination problems must be solved. (3) Observatory in spacecraft modules, serviceable by rendezvous with space station or rendezvous by shuttle craft from space station or ground. Service could be performed in a pressurizable hangar or by docking with and entering a pressurizable compartment. This mode appears to be the most attractive at the present time. (4) Observatory reentry spacecraft, serviced by automated return to Earth and subsequent relaunch. This is an unlikely approach for very large instruments.

Critical Issues

Several critical issues arise:

1. Should astronomical instruments be launched in "monolithic" or "modular" form?
2. Can dim light astronomy be done in sunlight?
3. How are large diffraction-limited optical systems best built? Segmented or solid? Passive or active?
4. What are the advantages and disadvantages of the Moon as an observatory site?
5. Is man merely *useful* to the space astronomy program or is he really crucial and to what extent?
6. What is the relative cost effectiveness of possible modes of manned attendance of observatories, considering both the probability of low-cost transportation and other nonastronomical uses of man in space?

HIGH ENERGY COSMIC RAY PHYSICS

The cosmic ray physicist studies the energetic particles reaching our solar system, some of which possess energies higher than are ever envisioned as being attainable on Earth. These particles are the only sample of matter which comes to us from other parts of the galaxy or outside.

The study of the energy spectrum, nuclear composition, charge spectrum, and possible directionality of this radiation will certainly yield invaluable insights into the nature of the universe, including the synthesis of the elements, nuclear processes in stars, the mechanisms responsible for supernovae, and matter and magnetic

field distributions in the galaxy. Since these particles are strongly interacting, small amounts of atmosphere create a background which tends to diffuse the primary information.

This factor, together with the long exposure times necessary to accumulate significant amounts of data, make a strong case for mounting a high energy cosmic ray facility in a manned orbiting laboratory. Balloons can carry limited weights, must remain below the top of the atmosphere, and provide maximum durations of only a few days. A manned laboratory can carry much larger weights completely above the atmosphere, and remain there for one or more years.

Small unmanned satellites have made measurements on the relatively abundant low energy cosmic rays. When one begins to observe the very high energy particles above 10^{10} eV, which become extremely scarce as the energy increases, large equipments with large apertures are required. It is just these high energy particles which are so interesting since they are unaffected by the magnetic fields of the Earth and the Sun. They carry valuable information regarding the galactic structure, not attainable by any other means.

A large cosmic ray space station facility will be able to

1. Determine the primary flux from 10^{10} to 10^{15} eV.
2. Determine the charge composition from 10^9 eV to the maximum energy limited by intensity and exposure time.
3. Search for antimatter.
4. Measure the isotropy of the radiation.
5. Determine accurately the electron and positron energy spectrum above 10^{10} eV and possibly observe its interaction with the 3° K radiation, starlight, and interstellar magnetic fields.

The instrumentation for high energy cosmic ray physics will also be used in the field of high energy particle physics, and is discussed later in "Space Laboratories."

EARTH SCIENCES AND APPLICATIONS

These disciplines encompass (1) the study of the Earth by remote sensors, and (2) the application of satellites for communication and traffic control.

Program

A substantial automated program now exists. The 1970-1975 period will see a further buildup of the present capabilities. There

will be operational communications satellites and meteorological satellites in both low altitude near-polar orbits and in synchronous there may well be an operational Earth resources satellite in polar orbit having ground resolutions of 100 to 200 feet in visible wavelengths. Unmanned research systems in both polar and synchronous orbits will be testing new instruments and measurement techniques.

In the succeeding decade, we see a number of substantial needs for improved performance. In meteorology, we will strive for a general understanding of the dynamics of weather and the energy balance of the Earth. This will require improved resolution in the visible and infrared for both imagery and spectral measurements. In Earth resources, attempts will be made to advance the areas of mineral resources and hydrologic surveys, particularly water management. Most large scale maps should be based on space data. In navigation and traffic control, the technology for handling trans-oceanic airplane routing (one mile accuracy) now exists. Capabilities for increased power and antenna aperture may be used to extend this to handling airports or more heavily travelled routes. In communications, direct broadcasting of television to homes is a possibility. Data collection systems could monitor many ground sensors (tens of thousands of fixed sensors, balloons, or buoys) and transmit the collected data to central stations.

Instruments and Requirements

The above programs call for observation of the Earth in broad areas of the spectrum using both active and passive techniques. In the Earth sensing area, the instrument requirements are in general an extension of earlier imagery, radiometry, and spectrometry capabilities to higher spatial and spectral resolution and better vertical sounding discrimination. New instruments may of course be expected.

For communications, navigation, and traffic control purposes, the need is to supply increased receiving and transmitting capabilities in space. This may include larger power supplies (tens of kilowatts), larger aperture antennas, and possibly new technology in some of the receiving and transmission systems. Orbits in use will include Earth synchronous and low polar.

Such a vigorous program seems inevitable, although the details cannot be foreseen at the present time. It should be remarked that

many benefits will become cost effective only on a global scale, and that there are political and legal difficulties (including, for instance, frequency allocations) to be overcome before fully operational systems can be implemented.

Given such a program, however, the implementation may be quite massive. Clearly, much of the activity could be carried on by automated satellites of a scale not much larger than now employed. On the other hand, a 3-meter telescope in synchronous orbit has been proposed as a tool in Earth resources; direct broadcast systems (20 to 50 kilowatts) are substantial; and there is an option to be examined of using integrated, multi-application spacecraft of large size, containing many instruments.

Roles of Man

As in the case of astronomy, the roles of man—or of manned spacecraft—should be resolved by economic studies. There is little support for man as a scientific operator; most functions can be pre-programmed or controlled from the ground. At the same time, it is admitted that a manned spacecraft should have windows and that the flight of an occasional scientific specialist should not be discouraged. However, obtaining applications data, whether experimental or operational, tends to be repetitive, prolonged, and peculiarly suited to automation.

In the applications area, there appear to be “natural” roles for man in the developmental phases of new instruments and in the proof of feasibility of measurement techniques. These are “laboratory” activities, where the man observes instrument performance, makes changes, and iterates. It should be noted that such functions are not particularly sensitive to geographic coverage, and need not be in the orbits of an “operational” system.

The developmental phase activity may be particularly pertinent when dealing with structures of great size or light materials, erectable only in zero gravity. This “role of man” is again a matter of economics; the Echo balloon and the 1500-foot antenna span of the Radio Astronomy Explorer show that simple structures can be deployed automatically.

As in astronomy, man can contribute to the Earth sciences and applications program by performing repairs, calibrations, alterations, and maintenance. For those instruments which are accessible to him (on a space station or via shuttle from space station or the

Earth), he can assure the quality of the data and extend the useful lifetime of sensors. Clearly there is a cost level at which outright (and automated) replacement is preferable to repair; conversely, if the more ambitious systems mentioned previously become reality, a manned service capability will be highly desirable.

Modes of Operation

The alternate modes for carrying on an applications program involve a combination of manned and unmanned systems.

The degree to which man can actually carry out the functions described above is unknown at this time. With further demonstration of man's space capabilities, the economic tradeoffs of manned test, repair, and assembly versus unmanned operation and replacement can be made.

Critical Issues

A number of economic questions arise:

1. Will it be more cost effective to fly operational devices on a manned spacecraft than on an unmanned spacecraft? If so, under what conditions?
2. What is the cost level at which repair of a satellite becomes preferable to replacement by a new launch?
3. What is the risk associated with space station size? That is, is there a size where too many resources depend upon a given facility?

It is not obvious that a single large facility is preferable to several small ones. Disadvantages of the large facility may include the following:

1. Dependence of a given device on the launch schedule of the facility; time sharing in flight; all instruments in a single orbit.
2. Radio frequency interference and related interactions.
3. Mechanical couplings; vibration, orientation, and translation between different experiments and operations.

Conclusion

It is likely that the best observatory program is a combination of manned and unmanned stations. The decision on the proper

combination should include consideration of economic factors. At this time we do not have the data to make this tradeoff. We recommend that appropriate studies be initiated to form a basis for such an evaluation.

SPACE LABORATORIES

An Earth orbiting manned space station will provide important new capabilities for the pursuit of basic and applied research programs in several areas of science which can be carried out completely on-board the station. The availability of skilled men who can function in the space station allows for designs radically different from those required for unmanned space experiments. It can result in lower experimental costs, broader flexibility in experimental objectives, increased reliability, and longer useful lifetimes for the experiments. In several of the areas with which this section is concerned, so little is known that many of the experiments must be heuristic in nature, and it is in precisely this milieu that man is most useful.

To use man properly in this role it will be necessary to have an orbiting laboratory. This may involve a series of coupled modules which can be changed from time to time as needs dictate. The station may also serve as a base from which additional unmanned orbiting satellites can be launched, controlled, or serviced.

In the following sections we discuss, in turn, three principal disciplines to be conducted within the space laboratory: (1) life sciences, (2) space physics, and (3) materials science and processing.

LIFE SCIENCES

Introduction

If man is to be an active contributor to the success of our long range space programs, it is essential to learn more about the effects of the space environment on him and his capabilities to perform in a wide variety of situations in space. The first requirement is to develop broadly based experiments designed to study the physiological and behavioral response of man to the space environment. Man's limitations and capabilities must be included in the important operational and design decisions necessary for advanced manned

space flight planning. The future space role of man in the life sciences will be treated here under four categories: aerospace medicine, biotechnology, space biology, and exobiology.

Unlike other aspects of the winter study program, the research required to "space rate" man under the subjects of aerospace medicine and biotechnology must be completed by the mid or late 1970's.

Aerospace Medicine

Under this heading we include two types of study: (1) that related to special vulnerabilities of man in the space or lunar environment, and (2) that related to the management of any disability not directly related to the peculiar environment.

In the first category our knowledge has scarcely reached its infancy. The demonstrations that man can perform successfully for up to fourteen days in space have shown that there should be no insuperable obstacles to his long term activities. However, man's powerful compensatory mechanisms tend to mask effects of a continuing stress until, after weeks or months, a whole system may abruptly collapse. Consequently, we should not be lulled into a sense of security by the superb short-term performance of the astronauts.

We must now embark on a comprehensive biomedical study to identify each function which may fail, its mode of failure, and practical means for detecting both its imminence and its prevention and treatment. This involves an appraisal of each body system including its limitations in performance. These requirements can best be met by enlisting the aid of the best physiological and medical centers of the country. The NASA components of this effort would include coordination of experiments and collection of data, together with distribution of useful information on special sensors and tests, and distribution of knowledge so gained to the whole biomedical community. Much of the actual experimentation as well as synthesis and interpretation of data would rest with these most competent nationally in this community.

There would be validation on the ground of all biomedical studies to be used in space together with pre-, intra-, and post-flight studies of all the personnel. The multiple special stresses of space may enhance each other's destructiveness; hence, they must in the final analysis be assessed in space flight itself, to the extent possible.

The possibility of any illness or injury increases with increasing flight duration and larger crew size. If a physician astronaut is included as crew member, he could be trained to deal with these exigencies. It is doubtful that he should be included only for this purpose; the availability of on-board television and telemetry of physiological data makes it possible to carry out diagnostic evaluation by ground-based physicians, who could direct treatment and employ consultants as necessary. Ground-based systems of remote diagnosis and treatment are now in existence and should be evaluated for effectiveness in the special conditions in space flight.

Biotechnology

The basic objectives of the biotechnology program are to optimize

1. Crew life support equipment, work and decision aids, and crew protective and safety systems both inside and outside the spacecraft.
2. Astronaut habitation in terms of living and working conditions. This includes spacecraft volume utilization, color/decor, clothing, personal hygiene, food preparation, recreation, duty-rest scheduling, interpersonal reactions, levels of illumination, thermal/humidity limits, atmosphere control, and waste management.
3. The role of the astronaut, both as a scientist and as an operator. This necessitates task performance measurements to determine the capabilities and limitations of man to perform useful work in space.

It must be emphasized that the long range requirements described above are shared with objectives of aerospace medicine and space biology. Very close cooperation among scientists working in these areas will be required. It will be necessary for NASA to insure interdepartmental communication and avoid duplication of effort.

As mission duration and crew size increase, it becomes necessary to recover useful materials from on-board wastes in order to reduce volume of stored resources and resupply requirements. Concurrently, as programs become more ambitious, additional demands are placed on the astronaut, necessitating improvement of all living and working conditions if he is to remain in space for long periods of time.

Astronaut performance in real operational situations can be assessed by such measures as task time-line, accuracy, and metabolic cost. It is important to recognize, however, that little information will be gained if the assigned tasks are relatively simple or prohibitively complex. Effort should be directed to identifying the borderline between what is feasible and what is not. Returned information can then be used to optimize man's contribution and to develop the appropriate technology to enhance man's proficiency.

Space Biology

In its broad definition, biology includes the study of man. In this discussion, however, we are reviewing the need for investigation in subhuman areas. We should utilize the unique features of the space environment (weightlessness, altered periodicities, and radiation) to analyze basic organism-environment relationships. These factors may well affect reproduction, growth and development, biological rhythms, and other physiological functions. These considerations must be subjected to experimental testing. Initially, most studies will involve cells, plants, and small animals.

Additional experiments should be performed to supplement the clinical studies related to evaluation of physiological functioning of man in space. Simple life forms, tissue cultures, and a range of vertebrates including mammals will all be used to provide supporting data. The use of techniques which exceed in complexity and hazards those which can be used with man, and the ability to sacrifice specimens offer distinct advantages here. Animal experiments to supplement clinical space research may be designed on the basis of anticipated predictive value regarding human performance, or as a follow-up after detection of physiological aberrations in manned flights. Jointly these experimental approaches can contribute substantially to medical and basic physiological knowledge and may bear directly on the problems of long duration manned flights. Man's role in space biology will be enhanced by his ability to carry out on-the-spot manipulative tasks and judgements.

Exobiology

The basic objective of exobiology is to detect the existence of extraterrestrial life, to study its origin and nature, and to assess its

level of development. This search will begin with detailed examination of returned lunar samples in Earth laboratories. The refined techniques developed should be exploited later upon planetary samples. Alternatively, search for possible organic materials on the Moon could be conducted in-situ.

A space station in Earth orbit provides a facility for the remote multispectral sensing of the planets in important wavelength ranges not accessible from inside the Earth's atmosphere. It is possible to evaluate planetary atmospheres for life support and seek emission or absorption patterns characteristic of life-associated molecules. Collection and analysis of micrometeoroids and interplanetary dust for possible simple organic and macromolecular content will be important objectives for a manned space station, but will require much more careful control of the dumping of human organic wastes overboard than presently employed.

Permanent lunar bases, if established for other reasons, would also provide a place to study possible toxicologic and pathogenic characteristics of returned planetary samples before their introduction into the terrestrial biosphere. Spacecraft sterilization becomes a critical matter with acquisition and return of lunar and planetary samples from the standpoints both of outgoing terrestrial and of incoming alien contamination.

Specific Considerations

We think that any significant work toward provision of artificial gravity should await the demonstration that it is needed; the zero gravity state may even be preferable to that of 1g. Contrariwise, we do know that the radiation from solar flares is harmful. We need to know more both about the prediction and precise physical nature of solar flares and the immediate and delayed effects of such radiation on the whole body of man.

Decisions regarding crew selection, crew size, and cabin habitability will require close and early cooperation among space scientists, engineers, and behavioral scientists. The long lead time associated with the developmental phase of long duration missions makes it imperative that biomedical personnel be involved early in planning.

We wish to re-emphasize that a firm commitment now to carrying out broad scientific studies of man and his capability to perform in space is crucial to planning the future space program in a

timely fashion. Our present scientific information is limited both in scope and in depth, and will require strengthening prior to moving on to long duration studies. This will require the development of a multi-disciplinary biomedical research effort, embracing both ground-based and in-flight studies, designed to provide the scientific base which will support future programs. This should be a basic research effort, free of specific operational requirements or mission orientation but guided by long term needs with the ground-based portions carried out almost in-toto in existing university facilities. Specific research needs should be identified and proposals solicited for solutions to basic problems. Finally we consider it imperative that the specific strategy appropriate to an orderly progression toward the stated objectives be evolved at once.

SPACE PHYSICS

High Energy Particle Physics

In addition to studying the nature of high energy cosmic ray particles themselves as discussed above under "Space Observatories," we are very anxious to *use* such particles to study their interaction with matter. Since this use concentrates on the reactions occurring *in the laboratory*, we discuss it in this section. While a 200 GeV proton beam will probably be operational early in the 1970's and a 200 GeV center-of-mass facility (equivalent to a 20 000 GeV proton beam) could be available in the late 1970's or early 1980's, useful cosmic ray energies reach fifty to one-hundred times the energy range of these machines, although the supply becomes extremely limited at these high energies. Orbiting facilities could answer some extremely important questions in the field of high energy physics. One could measure correlations among transverse momentum, longitudinal momentum, multiplicity, and total energy and match these measurements against predictions of current theories. The measurement of the proton-proton total cross section as a function of energy, done to 5 percent statistics, would establish the asymptotic behavior of the interaction, another quantity of extreme significance. Proton-proton and proton-neutron differential cross sections at high energies would settle numerous arguments. There is another set of answers within reach: Does the transverse momentum distribution law change at very high energies? How do weak interactions behave at these

energies? Are there heavy particles being created with large transverse momenta as some Earth-based experiments seem to indicate?

Cosmic ray physics and high energy particle physics research will share the same detectors which can be arranged in various configurations to perform different experiments. A large superconducting magnet of about three meters in diameter and a large nuclear calorimeter will be the primary instruments. The operation of this magnet would require either periodic supplies of liquid helium or the development of a liquid helium refrigerator or better superconducting alloys. Complementing the magnet there would be a liquid hydrogen target and a set of instruments such as proportional wire chambers, digitized readout spark chambers, large gas Cherenkov counters, plastic scintillators, etc. A very large (10 to 100 m²) array of gas proportional counters may also be desirable for the study of the extremely heavy (uranium region) cosmic nuclei.

While unmanned satellites of moderate size can study cosmic rays, they are severely limited in weight, versatility, and reliability. The increased payload possible on a manned station together with man to re-arrange and service the equipment provide far greater capabilities both for cosmic rays and for the study of high energy physics as well.

Magnetospheric and Solar Physics

Although studies of the magnetosphere will continue to be carried out by small, unmanned satellites, multiple systems with simultaneous measurements at several points in the near-Earth region will be required. The launching into precise orbit and the data collection and management of satellite fleets may turn out, on a cost-effectiveness basis, to be best implemented from man-operated space platforms.

Environment-modifying experiments, such as electron and ion injection into the magnetosphere, are important in understanding its geometry and the mechanism of wave propagation, particle diffusion, etc. Some of these experiments require large, complex equipment and operating procedures, and could most easily be performed from a manned station.

Other Physics Experiments

A variety of smaller experiments of considerable interest could be readily carried out on a manned station which would be difficult to automate. Cryogenically cooled detectors would permit definitive measurements of the 3° K space background radiation. Micro-meteoroids could be captured and chemically analyzed in situ. A facility, described in Appendix H—Materials Science and Processing in Space, would permit experimental research on the physics and chemistry of solids and liquids in zero-g.

Conclusions and Recommendations

We believe there are several branches of physics that could profit greatly by an orbital station. The priorities among these must still be assessed.

We feel that the presence of man in the space station will make possible the implementation of the programs described above; without man, useful physics programs in some areas can be continued but to a much more limited extent.

A manned space station is an excellent environment for the study of physics in and of space. The versatility offered by the astronaut, as well as his ability to re-configure, align, calibrate, and service equipment, makes his presence extremely desirable in the experiments of this section, although he is not required on a full-time basis. Many experiments can be operated in an automatic mode for extended periods of time.

MATERIALS SCIENCE AND PROCESSING

Opportunities Provided in Zero-Gravity

The unique property of the space environment of particular interest in this area is that of weightlessness or zero-g. The availability of large volumes of vacuum (although degraded near the spacecraft by leakage) and of solar radiation may prove useful adjuncts to zero-g.

Some possibilities of high potential value that are worthy of serious consideration, even though their ultimate development cannot be predicted with assurance, are the following:

In the 1g field on Earth, support and containment of a molten mass of material may introduce both physical and chemical contamination into the resulting solid.

In contrast, in a zero-g environment, much larger molten masses can be processed without making contact with any container or support. Large masses of arbitrarily low conductivity (such as ceramics) and refractory materials of very high melting points can be processed in this way.

Of particular interest would be the growth of large perfect crystals needed for industry or research by suspending the seed in solution, in the melt, or in contact with its vapor, thus avoiding any wall contact during growth.

Extreme supercooling made possible by freedom from walls as nucleation sites may also provide new material structures, such as superfine crystalline grains, or the glassy state in materials that normally crystallize during cooling.

In zone-refined crystals, the maximum crystal diameter is limited by the need to balance the gravitational pull on the molten zone by surface tension. This requirement disappears in zero-g permitting very large zone-refined crystals, and purification of materials, such as some metals, whose surface tension is too low to permit zone refining on Earth.

In the 1g field on Earth, differences in density caused by differences in composition or in temperature produce undesirable convection currents. There is evidence that such currents introduce dislocations in otherwise perfect crystals, so that in zero-g, where convection currents do not occur, the growth of dislocation-free crystals should be easier.

Another advantage in the lack of gravity is that components of different density in a melt or solution will not separate or settle out. This should permit casting certain new alloys, and will simplify casting composite structures where components of high density or strength, such as dislocation-free "whiskers," are cast into matrices of lighter and weaker materials. Using mixtures of solids and gases of different densities, new classes of alloys, colloids, and variable density solids or solid/gas mixtures may be realized. These include new foamed materials, possibly foamed steel for example, with very high strength-to-weight ratio.

Forming processes not possible on Earth appear feasible. In the absence of gravity, surface tension forces become very important. For example, materials in the liquid state rapidly take the form of perfect spheres under the influence of surface tension. Spherical

surfaces of superior smoothness and perfection may result from solidification of glassy materials or perhaps by rapid homogeneous nucleation of fine crystals from the melt by supercooling.

Thin wall membranes could be drawn out, stabilized by surface tension, and deformed in prescribed ways by electrostatic fields as they solidify. Castings, forgings, and long extrusions may have important new possibilities in zero-g.

Conclusion

An analysis of the influence which the space environment could exert on the processing of materials suggests that a materials laboratory would be a useful component of a space station. Identification has been made of a number of specialized materials having unique properties which can probably be produced only under space conditions. The initial emphasis should be upon research to understand how materials behave during zero-g processing and to identify new materials and fabrication methods to be used later. It does not appear that early emphasis should be placed upon actual fabrication of specific products.

We believe that the materials presently proposed as candidates for study are limited by the abbreviated current state of knowledge. It is our expectation that experience with zero-g processing will markedly expand our horizons and generate a much broader spectrum of possibilities.

Development of new materials and processes puts a particular premium on the presence of man as a modifier, controller, and manipulator of the experimental conditions. The course of experiments will be determined by early results. Only a man on the scene, with apparatus under his control, can react and modify the next experiments as required.

CONCLUSIONS

Space work during the coming few years can be oriented toward maximizing its apparent success and useful accomplishments over these years, or alternatively, it may primarily emphasize the development of maximum capabilities for the more distant future. In investment terms, these two extreme policies might be compared with investment for immediate income and investment for long-term capital gains. Clearly it is the proper balanced program which

must be chosen, since the importance of immediate returns as well as a successful long term space program are both evident.

There has been much debate, with overtones of ideology, over the relative merits of manned versus unmanned space work. We believe that such questions cannot be approached very well in abstract form, but that the merits of various types of techniques—manned, unmanned, ground based, or orbital—must be considered in the light of the objectives of each part of the space program, and with due consideration to both short-term returns and long-term development. While unmanned space work has not been discussed at length, we have tried in these proceedings to maintain in perspective both manned and instrumental approaches, with the hope that plans can be laid for a balanced and integrated program which best uses all potentialities.

The abbreviated nature of this study, as well as the inherent difficulty of prediction, makes it prudent to consider that some of the results of this study are very tentative in nature. Nevertheless, it is appropriate to list the following conclusions.

1. The benefits to the nation, both internal and international, dictate that the United States remain in the forefront of all major categories of space activity, including

- a. The space sciences
- b. Exploration of the solar system
- c. Manned space flight capability
- d. Economic applications of space flight.

2. It is reasonable to utilize 1/2 to 1 percent of the gross national product to support this nation's civilian space flight program.

3. Within the space flight program the following elements are of major importance and should be strongly supported:

a. An aggressive automated planetary exploration program as recommended by the Space Sciences Board of the National Academy of Sciences. Options must be kept open for a manned phase to follow the early automated phase.

b. An economic applications program of the general nature recommended by the 1968 Summer Study on Space Applications carried out by the National Academy of Sciences.

c. A continuation of lunar exploration following the Apollo landing as recommended by the Lunar and Planetary Missions Board of NASA.

d. A vigorous program of astronomical observations in Earth orbit along the general lines recommended by the Astronomy Missions Board of NASA.

e. The extension of manned space flight capability in Earth orbit to longer duration and to permit application for scientific and technological purposes.

4. The achievement of a manned low-cost transportation system is the keystone to the future development and large scale practical application of the space program. Development of such a system and plans for its effective use deserve high priority.

5. The use of a long duration manned space station appears to be a logical step in the evolution of manned space flight capability. It offers considerable potential support to the scientific and technological programs which appear desirable in a number of disciplines, and is necessary as a precursor to eventual manned planetary exploration. Such a space station should be designed to support men in the weightless condition unless unexpected biomedical problems are encountered or overwhelming engineering advantages for artificial gravity are discovered.

6. It is generally agreed that strong arguments exist for placing observatories and laboratories in Earth orbit. Large, complex facilities and instruments for astronomy, Earth applications, space physics, life sciences, and new materials development all have interesting potentials, and all can profit from manned attendance. Relative emphasis among these activities and the extent of manned attendance desirable in each must be decided by appropriate studies and early experiments.

Areas in which fruitful further studies could be conducted within NASA include the following:

1. Further investigation of the use of a lunar base for exploitation of the Moon.

2. Study of manned space flight systems which could be used to support payloads in geosynchronous orbit.

3. Further investigation concerning the alternate modes for manned maintenance and repair of payloads and satellites.

4. Analysis of the cost of equipment in space and of manning under the assumption of low-cost transportation with attention to

- a. Inclusion of all requirements and hence cost for man and his maintenance in space.

b. Past history of costs and present estimates for manned and unmanned equipment.

c. Examinations of reasons for the difference between the cost of ground and space apparatus with extrapolation into the 1975 era.

Other areas for study have been indicated earlier in these proceedings.

Finally, it should be pointed out that this discussion has attempted to consider the space program, with particular attention on its manned component, for the time period 1975-1985. In predicting the likely course of events more than a decade away, considerable wisdom and vision are required. The history of past attempts at such predictions shows that it is quite possible for this study to have fallen prey to the conservatism of the human beings who comprise its authors, and for our most visionary predictions to be far overtaken by the actual course of events.